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# ESTIMATION OF THE THREE DIMENSIONAL UNDERWATER AMBIENT NOISE FIELD FROM HORIZONTAL LINE ARRAY DATA

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## ABSTRACT

Several algorithms and techniques have been developed to estimate the horizontal directionality of ambient noise from horizontal line arrays. In most cases, the two-dimensional (2-D) representation of the array beam pattern is adequate to estimate the ambient noise horizontal directionality. However, when significant amounts of the noise are distributed out of the horizontal plane, a 2-D representation of the noise field can be misleading. An algorithm is described herein that utilizes the 3-D conical nature of the beam response patterns of the towed array and an iterative technique to estimate the 3-D ambient noise directionality. The algorithm is described and results from actual at-sea measurements are presented. This work was supported by funding from the ASW Environmental Acoustic Support (AEAS) Program of the Office of Naval Research.

## INTRODUCTION

An algorithm to estimate the three dimensional (3-D) ambient noise field has been developed that utilizes horizontal line array beam noise data on multiple array headings as the basic data input. Several measurement/processing techniques have been developed to estimate the horizontal directionality of ambient noise from horizontal line arrays<sup>1,2</sup>. In most cases, the 2-D representation of the array beam pattern is adequate to accurately estimate the horizontal directionality<sup>1</sup>. When significant amounts of the noise are distributed at elevation angles well off the zero elevation angle, use of the 3-D structure of the beam patterns and a priori information about the noise vertical arrival structure greatly improve the estimate of the horizontal directionality (2-D noise field)<sup>2</sup>. Unfortunately, the 3-D noise field is not estimated. When the vertical component of the noise changes as a function of azimuth, as is generally the case when shipping noise is an important contribution, the true 3-D conical beam response pattern needs to

be implemented so that the noise energy will be accurately distributed in elevation as well as in azimuth. The algorithm described herein is an iterative process that uses the true 3-D conical nature of the horizontal line array beam response pattern during the 3-D ambient noise directionality estimation process.

In order to formulate the ambient noise 3-D estimation algorithm, the primary equation that transforms the spherical coordinates of the noise field into the conical coordinates of the array will be presented. The formulation of the technique is provided in a sufficiently general nature to handle deviations from the array axis including an arbitrary array tilt. Finally, actual results from a recent noise field measurement exercise will be used to demonstrate the capability of the 3-D ambient noise field estimation algorithm.

## BACKGROUND

The line array, because of its relatively low cost and ease of deployment, is often used to measure the undersea ambient noise. Furthermore, the towed horizontal line array, with its added advantage of mobility, has achieved a high degree of utilization by researchers. The major disadvantage of the line array is that it can only distinguish the acoustic arrival angle relative to the axis of the array. It cannot uniquely determine the spherical coordinates of the arrival angle of the sound. The resulting ambiguity in angle of arrival describes a cone with apex at the center of the array and its center axis oriented along the axis of the array. The arrival angle of the sound relative to the array axis is half of the cone apex angle. This is illustrated by the representation of the towed array in Fig. 1 and the superimposed 3-D beam response patterns. Because of the vertical stratification of the acoustic propagation field in the ocean, the various beams of the line array sample different noise field and acoustic propagation regimes, i.e. SOFAR channel (RRR) and boundary interacting (RSR).

The complex nature of the coupling of the reception characteristics of the line array (conical beams) with the spherical structure of the noise field is partially illustrated by Fig. 1. However, it is illustrated better in Fig. 2 in which the noise sphere is represented as a flat surface and the beam response "footprints" of both a horizontal line array on a heading of  $270^\circ$  with a few degrees of array tilt (solid curves) and a vertical line array (dashed horizontal lines) have been superimposed. Only the footprints of the horizontal line array have both elevation and azimuth angle dependencies. Therefore, it should be possible to estimate both the azimuth and the elevation angle dependence of the noise from horizontal line array data when measurements are made on several different headings. A slight tilt of the array as illustrated in Fig. 2 is desirable to eliminate upward-downward ambiguities. It is very difficult to balance the array well enough that it always stays perfectly horizontal. Hence, some degree of tilt is generally a natural consequence of the measurement process.

The undersea ambient noise field at a given location can be expressed as a function of time and spherical angles in the following form:

$$N(\Theta, \phi, t) = N(\Theta, \phi) + \mu(\Theta, \phi, t) + \epsilon(\Theta, \phi, t) \quad (1)$$

where

$t$  = time

$\Theta$  = azimuth angle in spherical coordinates

$\phi$  = elevation angle in spherical coordinates

$N(\Theta, \phi, t)$  = measured noise power at a given frequency

$N(\Theta, \phi)$  = pseudostationary background ambient noise

$\mu(\Theta, \phi, t)$  = time dependent component of the ambient noise due to fluctuation in propagation, noise source movement, changes in noise source levels.

$\epsilon(\Theta, \phi, t)$  = errors in measurements due to flow noise, non-straight array, calibration errors, etc.

In an ideal measurement  $\epsilon(\Theta, \phi, t)$  is eliminated. Various measurement and data processing techniques have been developed to

minimize its effects in the results.  $\mu(\Theta, \phi, t)$  can be ignored if only the pseudostationary component  $N(\Theta, \phi)$  is desired. It is this pseudostationary component that can be expected to repeat on a seasonal basis year after year, when the noise source distributions and acoustic propagation conditions are again the same. It is this term that can be used in the predictions of the noise for future times, and it is also this term which the technique presented herein attempts to estimate.

The technique for estimating  $N(\Theta, \phi)$  is based on beam noise data measured by a horizontal line array. This can be expressed mathematically as:

$$R_{i,j} = \frac{1}{T} \int_0^T dt \int_0^{2\pi} d\Theta \int_{-\pi/2}^{\pi/2} N(\Theta, \Phi, t) b_i(\Theta - \Gamma_j, \Phi) \cos\Phi d\Phi \quad (2)$$

where

$R_{i,j}$  = beam output noise powers averaged over a time  $T$ ,

$i$  = beam number,

$j$  = array heading number,

$\Gamma_j$  = the array heading angle, and

$b_i(\Theta, \phi)$  = power response of  $i$ th beam.

### APPROACH

The horizontal line array can determine the arrival angle  $X$  of a signal relative to the axis (or line) of the array, but it cannot determine the absolute orientation in space. Hence, all orientations give the same response as long as the arrival angle relative to the array axis is the same. The resulting beam pattern of such an array response is conical, which intersects a concentric sphere in a circle as illustrated in Fig. 3. The noise field on the other hand, is more naturally described in terms of spherical coordinates. The mathematical representations of the conical beams of the line array and the spherical nature of the noise field are basically incompatible. This incompatibility must first be overcome before an efficient algorithm can be developed to estimate

the spherical noise  $N(\Theta, \phi)$  from conical data  $R_{i,j}$ . This incompatibility is overcome by Equation (3) which transforms the noise power at spherical angles  $\Theta$  and  $\phi$  into noise at the conical angle  $\beta$ :

$$\beta = \cos^{-1} \{ \cos \Theta \cos \Phi \cos X + \sin [\cos^{-1}(\cos \Theta \cos \Phi)] \sin X \sin [\tan^{-1}(\sin \Phi / \cos \Phi \sin \Theta)] \} \quad (3)$$

The estimation of  $N(\Theta, \phi)$  is an iterative one that begins with assuming an estimated noise field  $N_0(\Theta, \phi)$ . The simplest possible form is a constant, which corresponds to an isotropic noise field (e.g.  $N_0(\Theta, \phi) = C$ ). Next  $N_1(\Theta, \phi)$  is convolved with the beam patterns of the array, using equation (3), to get estimates  $R'_{i,j}$  for  $R_{i,j}$ . The differences  $D_{i,j} = R_{i,j} - R'_{i,j}$  are used to either add noise to or subtract noise from  $N_0(\Theta, \phi)$  at the appropriate locations  $\Theta$  and  $\phi$ . When this has been done for all  $i$  beams and  $j$  array headings, a new estimate  $N_1(\Theta, \phi)$  has been created. This process of convolution and noise field modification is continued until the differences fall below a predetermined threshold, and then the final noise field estimate  $N_f(\Theta, \phi)$  is accepted as the estimate for  $N(\Theta, \phi)$ .

## RESULTS

Beam noise data from a line array on different headings in the undersea ambient noise field were processed by the 3-D noise field estimation algorithm. The results are presented in Fig. 4. The noise levels as a function of elevation angle  $\phi$  and azimuth angle  $\Theta$  are plotted in gray scale contours with the level increasing with darkness. The horizontal directionality of the noise  $N(\Theta)$  is one statistical characterization of the noise field that a 2-D estimation algorithm would attempt to generate. In the case of the 3-D noise field, it can be obtained by merely summing over all vertical angles  $\phi$  at each azimuth angle  $\Theta$  (bottom plot in Fig. 4). The curves in the rectangular plot to the right in Fig. 4 are vertical profiles of the total noise and of two small azimuthal sectors, one in a direction of high level noise ( $\Theta = 290$  deg) and one in a direction of low level noise ( $\Theta = 150$

deg). The vertical profile of the total noise is generally obtained from measurements by a vertical line array. In this case, it was obtained by summing over all azimuth angles  $\Theta$  at each elevation angle  $\phi$ . The other two vertical profiles are for small sectors in  $\Theta$  that could not be measured by either a vertical line array or a horizontal line array. In fact, the measurement of those profiles would normally require a high resolution volumetric array with an extremely narrow beam pattern, something that presently does not exist.

## SUMMARY/CONCLUSIONS

A technique for using towed horizontal line array beam noise data measured on multiple headings of the array has been developed. It utilizes an iterative technique that compares measured beam noise data with corresponding results obtained from convolving the beam noise patterns with an estimate of the 3-D noise field to guide modifications of the noise field estimate. Once the final estimate is obtained, it is then possible to investigate characteristics of the noise field that are essentially invisible to the array that acquired the original beam noise data, such as the vertical directionality of the noise in azimuthal sectors that otherwise would require a high resolution volumetric array to measure.

## REFERENCES:

1. R. A. Wagstaff, "Iterative Technique for Ambient-Noise Horizontal Directionality Estimation From Towed Line-Array Data", J. Acoust. Soc. Am. 63, 863-869 (1978).
2. R. A. Wagstaff, "Horizontal Directionality Estimation Considering Array Tilt and Noise Field Vertical Arrival Structure", J. Acoust. Soc. Am. 67, 1287-1294 (1980).

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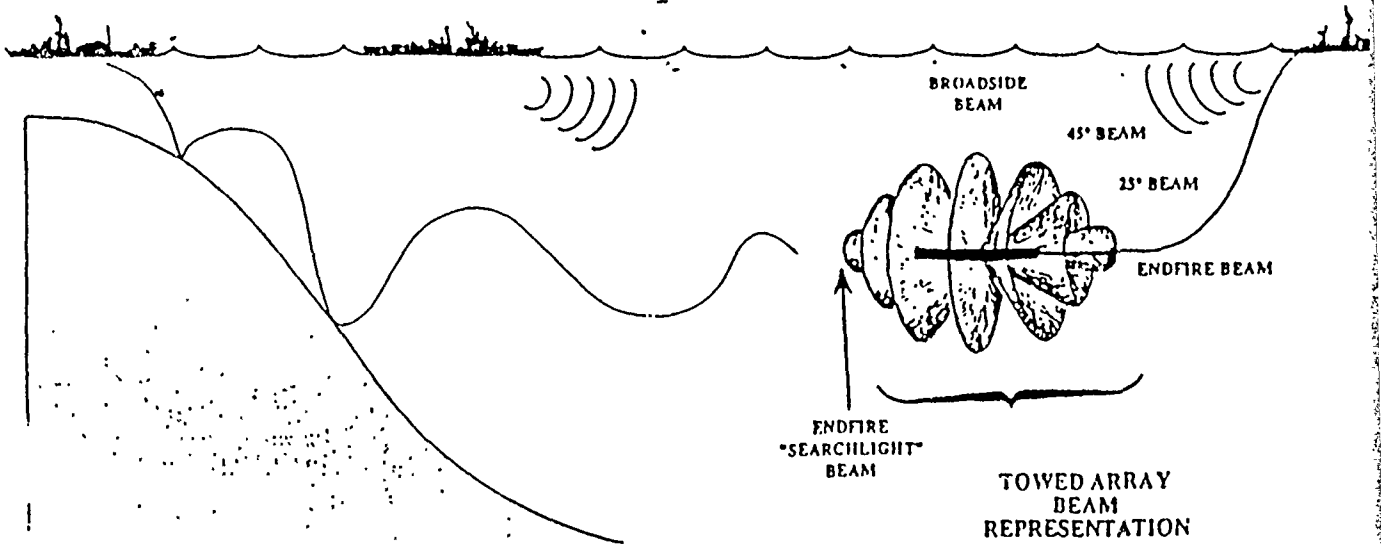


Figure 1. Representation of a towed horizontal line array measuring undersea ambient noise.

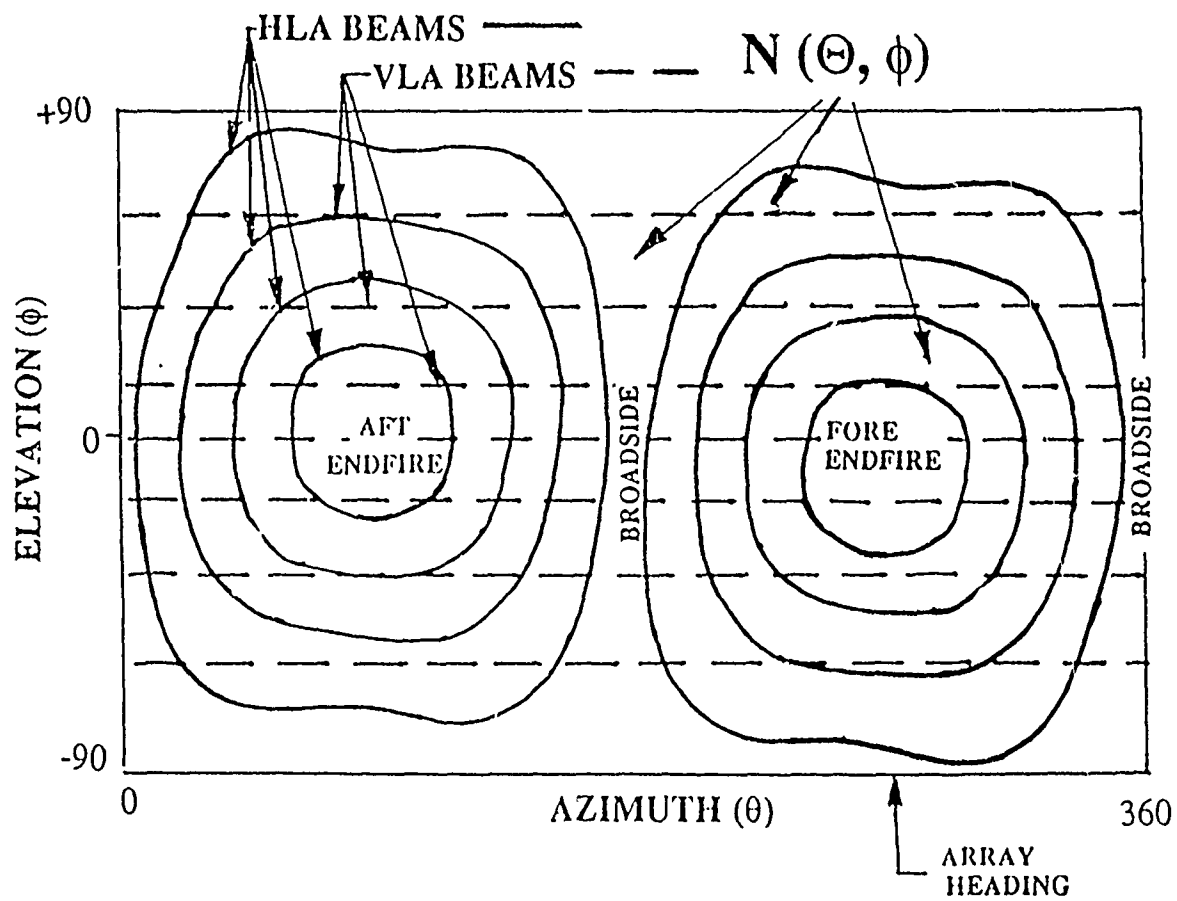
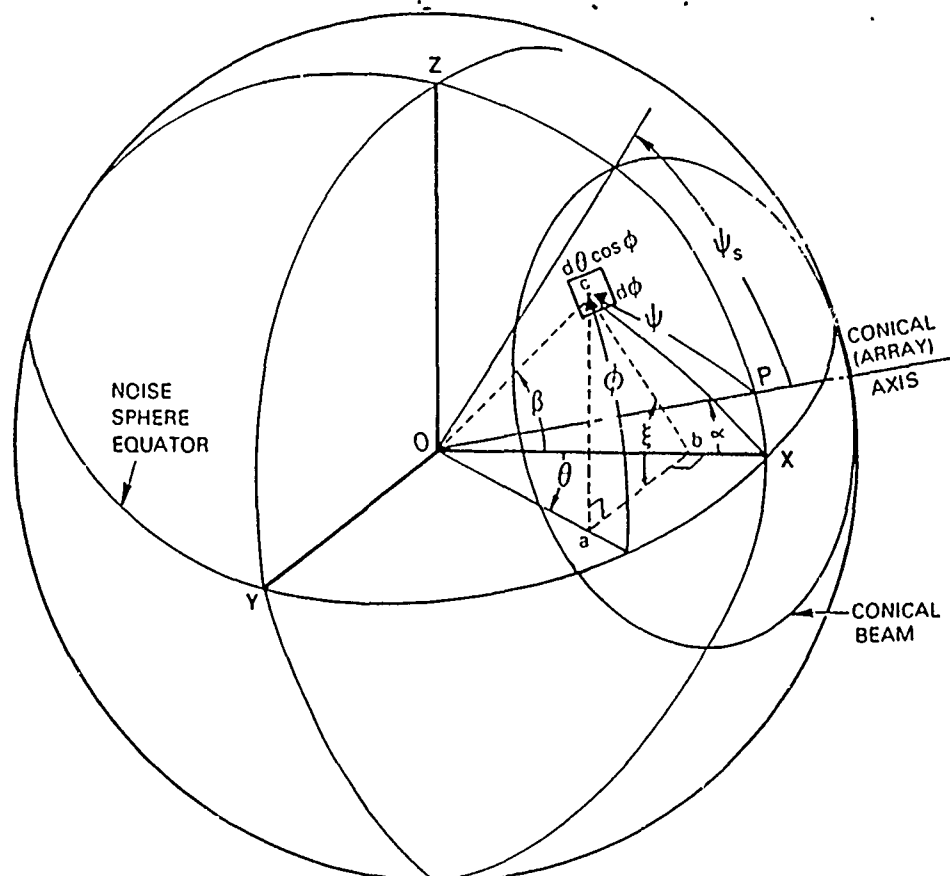


Figure 2. Representation of a spherical noise field  $N(\Theta, \phi)$  and the conical "footprints" of the vertical line array (VLA) and the tilted horizontal line array (HLA) on a plane surface.



- $\theta$  AZIMUTH ANGLE
- $\phi$  VERTICAL ANGLE
- $\alpha$  ARRAY TILT ANGLE
- $\psi$  CONICAL ANGLE
- $\psi_s$  STEERING ANGLE

Figure 3. Coordinate system for the noise sphere and the conical beams of the line array.

# 3 DIMENSIONAL NOISE FIELD

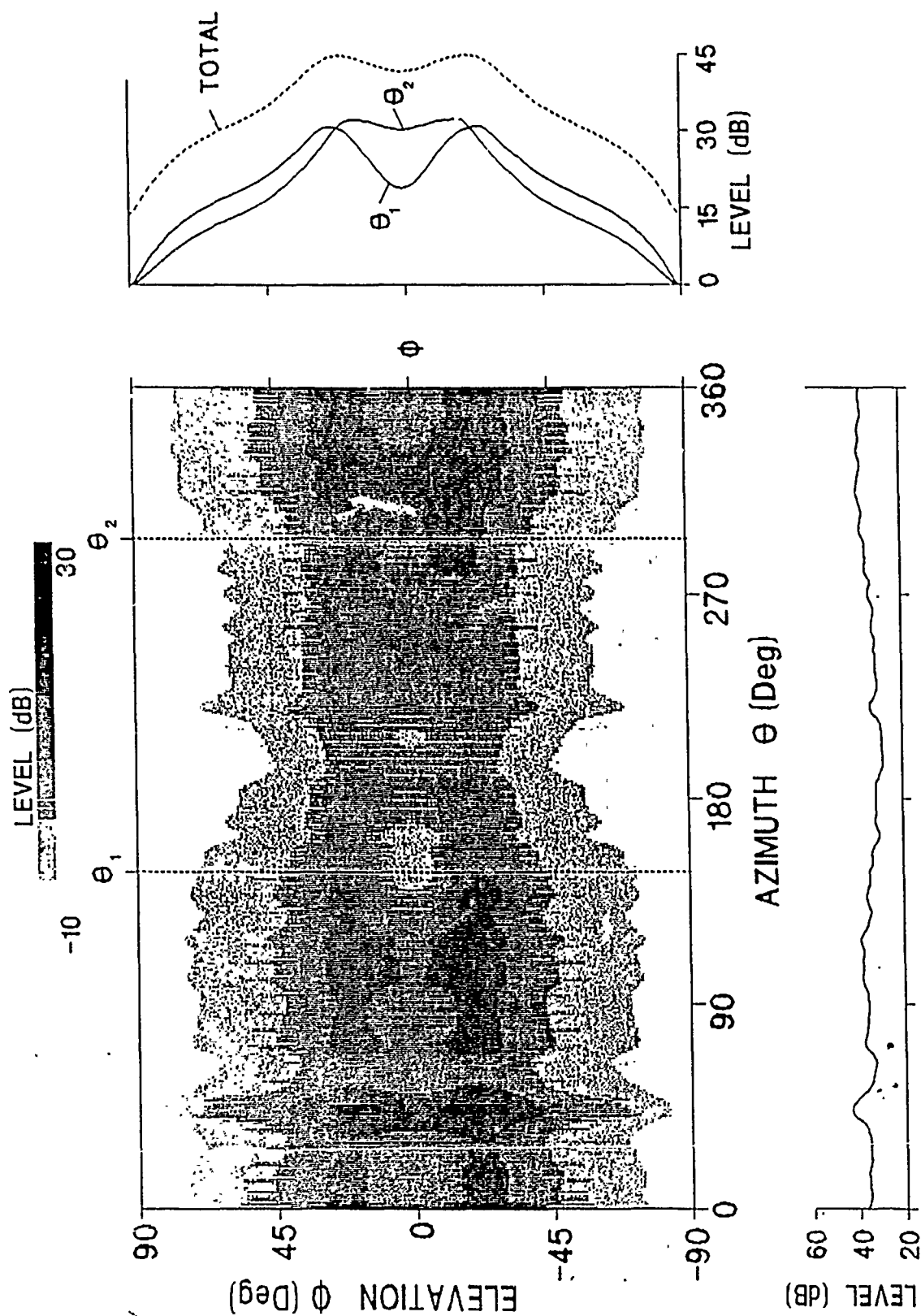


Figure 4. 3-D noise field estimate (gray scale contour plot) with corresponding 2-D horizontal directionality (bottom) and vertical profiles for the total noise and two small azimuthal sectors, one noisy ( $\Theta_2$ ) and one quiet ( $\Theta_1$ ).